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Predictions of Heating and Cooling Energy Demands for Different Building Variants with Conventional Building Fabric and Selected Fabric Interventions

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KEYWORDS
building variants, energy simulation, ESP-r, energy demand, fabric interventions

ABSTRACT

An energy simulation package, Environmental Systems Performance-research (ESP-r) was used to predict the energy performance of selected building variants, which consist of one typical UK school, two three-storey estate agent and small offices, two single-storey convenience stores and fifty double-storey semi-detached dwellings. Building models were created and construction details, internal casual gains, occupation patterns, heating and cooling system controls were defined for each building variant, in accordance with the original building specifications. Simulations were carried out using Birmingham climatic data for a complete calendar year and were repeated with selected fabric interventions to replace conventional building fabrics. The resulting heating and cooling energy demands for the building variants were predicted and presented for selected days in winter and summer as well as for the whole calendar year. Dwellings account for up to 79% or more than three times that of the total heating energy demand required for the combined buildings. With the application of fabric interventions, such as, EPS and polyurethane board, the heating energy demands of the combined buildings were reduced with a saving of approximately 200320kWh or nearly 10% per year.

1. INTRODUCTION

Buildings have significant long-term impacts on the environment due to their period of operation which range at a minimum from several decades to centuries. Decisions on the choices of building materials thus, require careful consideration. Domestic buildings account for 29% of the final energy consumption in the UK in 2006 [1]. The major concern in the building sector is the increasing energy requirement for space heating, cooling and ventilation, water heating, lighting and electrical appliances. The energy loads of the buildings can be reduced with the application of fabric interventions, such as, advanced glazing systems, opaque and transparent insulation materials [2].

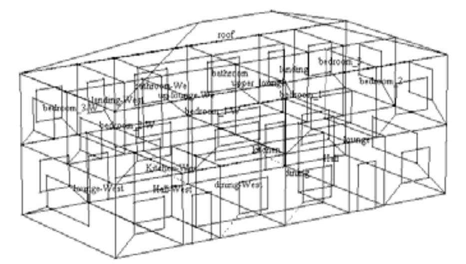
In the present study, five different types of buildings have been selected from the existing building stock. They include both domestic and non-domestic buildings and cover the majority of the buildings constructed in the UK over the past 100 years. The energy simulation package, ESP-r, has been used to predict the energy performance of the buildings with original building façade materials. The simulations were repeated with these conventional building materials replaced and augmented by various technological interventions [3,4] to provide reduced fabric U-values. The interventions include increased insulation materials for external walls, ground floors and roofs and the use of argon-filled triple glazing for windows.

2. DETAILS OF THE SELECTED BUILDINGS

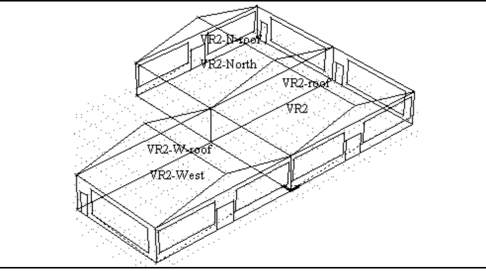
The five different types of existing buildings selected are a double-storey semi-detached dwelling, a single-storey convenience store, a three-storey building (estate agent and small office) and a secondary school, as shown in Figure 1. The dwelling was constructed from 1945 to 1964, whilst the convenience store was constructed pre-1900. The convenience store accounts for 32% and 22% of the retail building stock in the UK by age of construction (pre-1900) and floor area (100-250m^2), respectively [5]. The construction type of the school accounts for 35% of the existing secondary school building stock by student numbers (1001-1500 students category) [6]. Both the small office and estate agent were located in a three-storey building situated on a high street, constructed using locally available building materials. Small offices account for 5% and 17% of the office building stock in the UK by age of construction (1900-1918) and floor area (100 to 250m^2), respectively [7]; whilst, the estate agent accounts for 9% and 15% of the retail building stock in the UK by age of construction (1900-1918) and floor area (50 to 100m^2) [5]. The simulations of energy use were conducted for a selected suburban site away from the city centre in Birmingham. It was assumed that the site has 50 dwellings, two three-storey buildings that consist of the estate agents and small offices, two convenience stores, and one secondary school. The energy requirements for the group of buildings were assessed with the original conventional construction materials. The simulations for the same buildings were repeated to investigate the impact of the fabric interventions on the energy requirements of the buildings.

3. ASSUMPTIONS

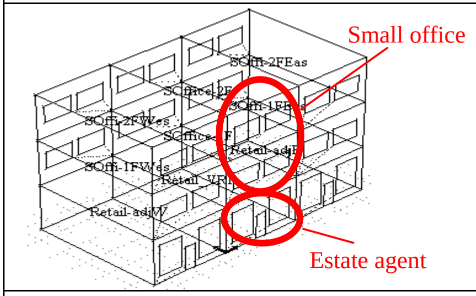
The simulations were conducted using Birmingham climatic data for all building variants. The building occupancy patterns, ventilation and infiltration rates vary according to building type, details are listed in Table 1, and are defined to allow realistic predictions to reflect real building operations. The patterns of heating and cooling in the buildings reflect realistic environmental controls and aim to achieve thermal comfort temperatures (between 20°C and 25°C). Table 2 shows the details of heating and cooling systems, including the operating schedules, heating and cooling system capacities and temperature set points defined to control the heating, ventilation and air conditioning (HVAC) system of the different buildings.



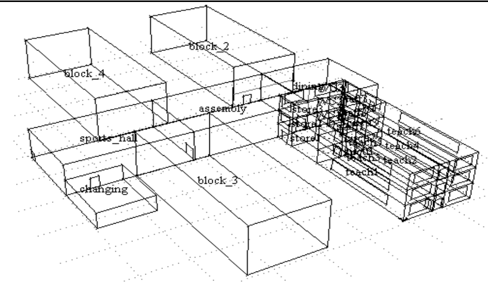
A double-storey semi-detached dwelling, constructed between 1945-1964



A single-storey convenience store, constructed pre-1900, with adjacent buildings



Small office and estate agent, constructed between 1900-1918



Secondary school, constructed in 2004

Figure 1 Wire frame drawings showing the different types of building variants

Table 1 Occupancy, ventilation and infiltration assumptions for building variants

Building variants	Area (m^2)	Air change per hour (ach)		Occupancy rates	
		Ventilation	Infiltration	Schedules	person per m^2
School	9438	Up to 2.86	0.3	Mon to Fri, 9am to 4pm	7.3
Estate agent	60	1.05	0.58	Mon to Sat, 9am to 7pm	8.6
Convenience store	150	7.2	1.0	Mon to Sun, 8am to 10pm	5.0
Small office	120	1.05	0.58	Mon to Fri, 9am to 7pm	9.23
Dwelling	144	1.38	0.76	Mon-Sun, after office hour	36

Table 2 Proposed operating schedule for heating, ventilation and air conditioning (HVAC) systems for all building variants

Building variants	Day	Start time	End time	Set point (°C)		Capacity (W)	
				Heating	Cooling	Heating	Cooling
School	Mon-Fri	09:00	16:00	19	21	15000	15000
Estate agent	Mon-Sat	09:00	19:00	21	23	3000	3000
Convenience store	Daily	08:00	22:00	21	23	32000	32000
Small office	Mon-Fri	09:00	19:00	21	23	3000	3000
Dwelling	Daily	23:00	06:30	15	-	7000	-
		06:30	08:30	19-22	-	15000	-
		08:30	17:00	15	-	7000	-
		17:00	23:00	19-22	-	15000	-

During the summer (from the 16th of July to the 31st of August) and Christmas (from the 18th to 31st of December) holidays, there was no occupancy in the school. Thus, no heating and cooling systems were activated during these periods. In the semi-detached dwellings, no cooling system was used to meet the standard practice in the UK. A higher heating set point temperature was specified when the occupants are occupying the house after working hours, whilst a lower set point temperature was specified during other hours to maintain thermal comfort in the building. The internal casual gains from both equipments and occupants also contribute to heating and cooling energy loads of the buildings. The quantities, types, operating schedules and casual gains of different electrical equipments used were defined, whilst the energy gains from the occupants were calculated in accordance with CIBSE Guide A [8].

4. CONVENTIONAL BUILDING MATERIALS AND PROPOSED FABRIC INTERVENTIONS

The initial construction details specified for the building fabric used for external walls, roofs, ground floors and windows of the building variants were conventional brickwork, glazing and insulation materials. Most of the existing building variants are more than 50 years old and require major refurbishment, to reduce the energy loads of these buildings. Details of the original building fabric materials for the building variants are listed in Table 3. A number of technological interventions have been proposed [3,4], either replacing the old building fabric materials or improving the energy efficiency of the existing building fabric. The interventions include the use of expanded polystyrene (EPS), with a conductivity of 0.036W/mK and polyurethane board insulation materials for external walls, roofs or ground floors. The windows of the buildings were also replaced with double-glazed or argon-filled low-e coated triple-glazed windows. This paper presents the simulation results for only the fabric intervention of installing EPS and polyurethane boards detailed in Table 3. The significant reduction in the calculated U-values of the respective building elements that results from the application of the interventions is also shown in Table 3.

5. PREDICTIONS OF ANNUAL HEATING AND COOLING ENERGY DEMANDS

The heating and cooling energy performance of all building variants was assessed individually and as a group for a complete calendar year. The heating and cooling energy demands required for the building variants to achieve the target thermal comfort with temperatures between 20°C and 25°C were predicted. Figure 2 shows the predicted annual heating and cooling energy demands of the building variants with the original fabric, which were assumed, located at a suburban site outside the city centre. Higher heating energy demands were predicted for all buildings in the winter months (October to March), whilst cooling dominates in the summer months for all building variants except the dwellings (June to August). The total heating energy required for the 50 dwellings was most significant in winter months, with a maximum peak load of nearly 215000kWh predicted in January, more than three times the heating energy required for the school. Both dwellings and school building account for more than 85% of the total heating energy demands compared to other building variants.

Table 3 Existing building fabric and proposed improved fabric for all building variants

Buildings	Elements	Original fabric	Thickness	Improved fabric	Thickness
Secondary school	External walls	Outer brick Air gap Mineral fibre Breeze block Plasterboard U-value (W/m^{2}K)	100mm 50mm 50mm 100mm 12.5mm 0.51	Outer brick Air gap EPS Breeze block Concrete render U-value (W/m^{2}K)	100mm 50mm 150mm 100mm 13mm 0.175
	Roof	Aluminium Mineral fibre Ceiling tile U-value (W/m^{2}K)	100mm 165mm 10mm 0.22	Aluminium EPS Ceiling tile U-value (W/m^{2}K)	100mm 300mm 10mm 0.098
Estate agent and small office	External walls	Sandstone Lathe & Plaster U-value (W/m^{2}K)	305mm 12.5mm 2.71	Sandstone EPS Plasterboard U-value (W/m^{2}K)	305mm 100mm 12.5mm 0.267
	Roof	Mineral fibre Plasterboard U-value (W/m^{2}K)	100mm 12.5mm 0.33	EPS Plasterboard U-value (W/m^{2}K)	200mm 12.5mm 0.145
Dwelling	External walls	Outer brick Mineral fibre Inner brick Plasterboard U-value (W/m^{2}K)	100mm 50mm 100mm 12mm 0.53	Outer brick Polyurethane board Inner brick Plasterboard U-value (W/m^{2}K)	100mm 100mm 100mm 12mm 0.26
	Ground floor	Carpet Chipboard Air gap Concrete Gravel Earth U-value (W/m^{2}K)	6mm 19mm 50mm 150mm 150mm 250mm 0.86	Carpet Chipboard Polyurethane board Concrete Gravel Earth U-value (W/m^{2}K)	6mm 19mm 50mm 150mm 150mm 250mm 0.377
	Roof	Slate Roofing felt Plywood U-value (W/m^{2}K)	15mm 5mm 12mm 3.52	Slate Roofing felt Polyurethane board Plywood U-value (W/m^{2}K)	15mm 5mm 200mm 12mm 0.144
Convenience store	External wall	Brickwork Plaster Air gap Plasterboard U-value (W/m^{2}K)	170mm 30mm 50mm 12.5mm 1.45	Brickwork Plaster Air gap EPS Plasterboard U-value (W/m^{2}K)	170mm 30mm 50mm 50mm 12.5mm 0.431
	Floor	Tiles Concrete Clinker Earth U-value (W/m^{2}K)	6mm 150mm 150mm 250mm 1.10	Tiles EPS Concrete Clinker Earth U-value (W/m^{2}K)	6mm 100mm 150mm 150mm 250mm 0.249
	Roof	Mineral wool Plasterboard Air gap Plasterboard U-value (W/m^{2}K)	100mm 12.5mm 50mm 12.5mm 0.34	EPS Plasterboard Air gap Plasterboard U-value (W/m^{2}K)	200mm 12.5mm 50mm 12.5mm 0.14

The simulations were repeated for the buildings with fabric interventions to improve U-values and reduce building energy demands. Figure 3 shows that the maximum heating energy demand of the dwellings was reduced from 215000kWh to less than 195000kWh in January with the improved building fabric. Significant reduction in heating energy demands were also predicted for the other buildings, demonstrating the effectiveness of fabric interventions in reducing heating energy demands for all the building variants.
When the building variants were analysed individually, a maximum heating energy demand was predicted for the school due to it having the greatest occupied area. However, fabric interventions achieve the greatest improvement for the small office with a reduction of 76% heating energy (Table 4). In a suburban site with 50 dwellings, two convenience stores, two estate agents, two small offices and a secondary school, the heating energy required for the dwellings and the school account for up to 71% and 16% of the total heating energy demands for the combined buildings (Table 5). The predicted heating energy required for all building variants was significantly reduced, by the application of insulation to improve the fabric. A total saving of 153470kWh of energy for heating was predicted for the dwellings. The heating energy demands of the combined buildings were reduced with a saving of approximately 200320kWh or nearly 10% per year.

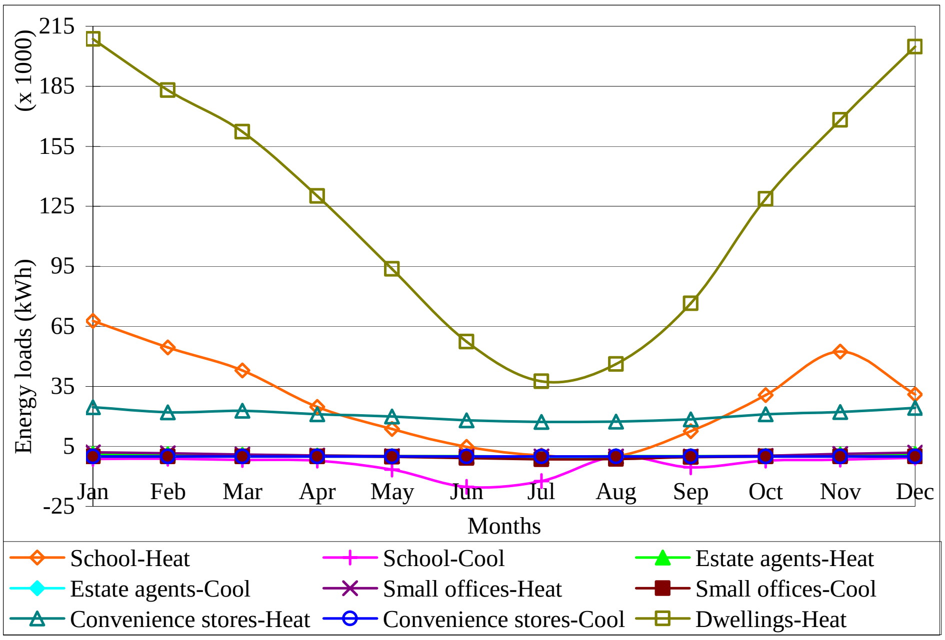


Figure 2 Annual heating and cooling energy demands for selected building variants with original building fabric construction

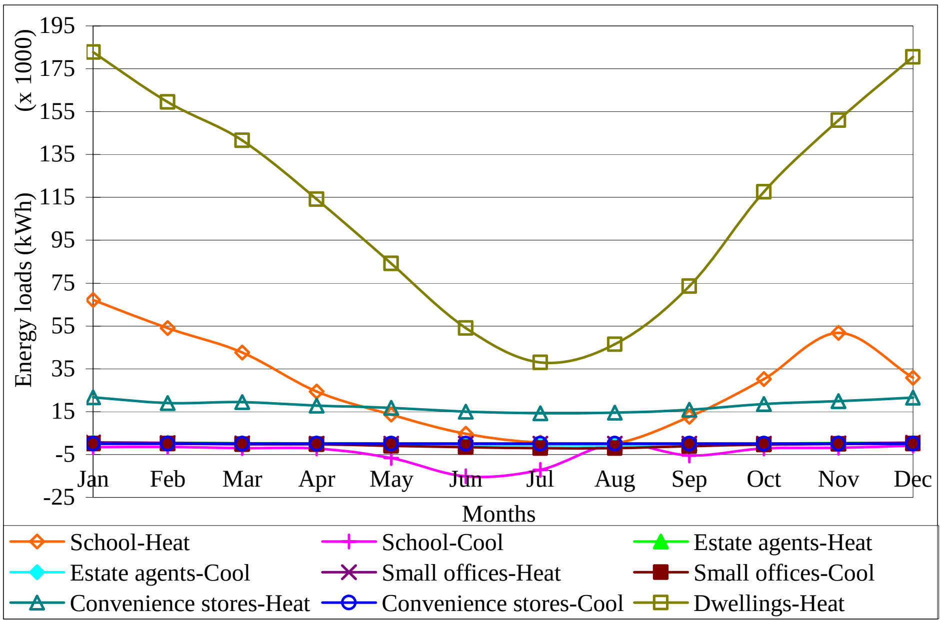


Figure 3 Annual heating and cooling energy demands for selected building variants with fabric interventions to reduce U-values

Table 4 Annual heating energy demand (kWh) for individual building variants with and without fabric interventions

Building variants	Annual heating energy demand (kWh)			
	Original fabric	Improved fabric	Differences	
School	334912	332344	-2568	-0.77%
Estate agent	3039	1318	-1720	-56.6%
Small office	4112	1003	-3110	-75.6%
Convenience store	124363	107052	-17311	-13.9%
Dwelling	29941	26872	-3069	-10.3%

Table 5 Annual heating energy demand (kWh) for selected building variants with and without fabric interventions

Building variants	No.	Annual heating energy demand				
		Original fabric		Improved fabric		Differences (kWh)
		kWh	% of total	kWh	% of total	
School	1	334913	16%	332344	17.5%	-2568
Estate agents	2	6078	0.29%	2637	0.14%	-3441
Small offices	2	8225	0.39%	2005	0.11%	-6219
Convenience stores	2	248725	11.9%	214104	11.3%	-34622
Dwellings	50	1497059	71.5%	1343589	70.9%	-153470
Total	57	2095000	100%	1894679	100%	-200320

The predictions show a significant potential saving in energy required for heating different types of existing buildings in the UK, when interventions, such as, EPS and polyurethane board are applied to the building fabric. These interventions are readily available in the market at affordable prices and achieve high standards of building energy efficiency. They can be easily applied to the fabrics of most types of existing buildings during refurbishment. In this study, where 50% or more of the total buildings are dwellings, the heating energy demand required for the dwellings during winter months is nearly three times the total heating energy demand required for all other types of buildings.

6. CONCLUSION

The building energy simulations show that, a significant reduction in the heating energy demand in the buildings studied resulted from the application of fabric improvements. EPS and polyurethane board if applied to the building fabric of all types of existing dwellings, school, office, and retail buildings can lead to significant potential saving in heating energy. In a suburban site which consists of approximately 50% to 70% dwellings, a 1000 student school and a mixture of office and retail buildings, the annual heating energy required by the dwellings is greatest being more than 50% of the total heating energy load of the combined buildings. Effort should be made to reduce the energy required in dwellings by the wide scale application of energy efficient fabric interventions, such as, EPS and polyurethane board. This single intervention can reduce the heating energy required by nearly 10% for the combined buildings.

Acknowledgement

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